Biogeographic Assessments of NOAA National Marine Sanctuaries: The Integration of Ecology and GIS Technology

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***Abstract*-The mission of NOAA's National Marine Sanctuary Program (NMSP) is to serve as the trustee for a system of marine protected areas, to conserve, protect, and enhance biodiversity. To assist in accomplishing this mission, the NMSP has developed a partnership with NOAA's National Centers for Coastal Ocean Science (NCCOS) to conduct biogeographic assessments of marine resources within and adjacent to the marine waters of all National Marine Sanctuaries over the next five years. NCCOS's Biogeography Program is leading the joint effort to define species distribution patterns and map associated habitats. Biogeography provides a framework to integrate species distributions and life history data with information on the habitats of the region to characterize marine resources in a sanctuary. The biogeographical data are integrated in a GIS to enable visualization of species' spatial and temporal patterns, and to predict changes in abundance that may result from a variety of natural and anthropogenic perturbations or management strategies. For example, the biogeographic assessment of three central/ northern California sanctuaries was used to delineate "hot spots" based on community metrics (e.g., biodiversity). In addition, accurate and highly resolved digital benthic habitat maps have been developed for Gray's Reef NMS to define species habitat utilization patterns to identify areas for special protection. Plans are to conduct assessments in all National Marine Sanctuaries over the next several years through utilization of the biogeographic process.**

I. BACKGROUND

The mission of NOAA's National Marine Sanctuary Program (NMSP) is to serve as the trustee for a system of marine protected areas, to conserve, protect, and enhance their biodiversity, ecological integrity, and cultural legacy. Since 1972, thirteen National Marine Sanctuaries, representing a wide variety of ocean environments, have been established, each with management goals tuned to their unique diversity (an additional site in proposed for the Northwestern Hawaiian Island Coral Reef Ecological Reserve). These goals may include restoration, monitoring, protecting healthy areas, and public education and outreach programs to generate understanding about the NMSP's role as a coastal steward. While some human activities in these marine protected areas are regulated or prohibited, achieving compatibility between conservation objectives and among multiple uses such as research, monitoring, commercial, and recreational activities is central to the design of the sanctuary system. Monitoring and managing this range of goals and activities requires an approach that integrates human use with ecology and geography. The science of biogeography can be used to support these complex management challenges, and to ensure successful stewardship of sanctuary resources.

Since establishment, many of the sanctuaries have witnessed increased pressure on marine resources from natural and anthropogenic phenomena, including climatic variation and degradation of habitats. In order for the NMSP to increase management capabilities, it is imperative that the spatial and temporal distributions of biota and habitats within sanctuaries be delineated. Thus, the NMSP has developed a partnership with NOAA's National Centers for Coastal Ocean Science (NCCOS) to conduct biogeographic assessments of marine resources within and adjacent to the marine waters of all National Marine Sanctuaries over the next five years [1]. The study of biogeography provides a framework to integrate species distributions and life history data with information on the habitats of the region to characterize marine resources in a sanctuary. When the biogeographic data are integrated into a Geographic Information System (GIS), it enables users to visualize spatial and temporal distributions, and to conduct ecological forecasts of potential changes in species distributions that may result from a variety of natural and anthropogenic perturbations. In addition, based on specific ecological metrics (e.g., species diversity), biologically significant areas can be delineated.

A. What Is Biogeography?

To understand how the NMSP can benefit from implementing biogeographic approaches to management, it is necessary to first define biogeography. A general definition of biogeography is: the study of spatial and temporal distributions of organisms and their habitats, and the historical and biological factors that produced them [2]. The complexity of products from biogeographic analysis range from simple distribution maps for a single species or a particular habitat, to more complex products that combine these simple data layers to create maps of biodiversity or habitat diversity [3] [4]. More commonly however, biogeographic products are even more complex and integrate several biological and physical parameters at once. For example,

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biogeographic analyses often integrate environmental variables with knowledge of organisms habitat affinities and physiological limitations [5] [6]. This can result in a type of biological "weather map" which is used to express the probability of encountering an organism in a given area [7] [8]. Other analyses may integrate the distribution of multiple species with some anthropogenic influence to determine how the biotic community is being affected [9] [10]. Still other products may focus on the changes in distribution of organisms or habitats through time. For example, the displacement of a native species by exotics can be analyzed in time series to predict future impacts and develop containment strategies. Even the response of organisms to global warming and sea level rise can be predicted and used to examine longer term management scenarios. These integrated products provide information not only on *where* specific organisms and habitats may be found, but also on *why* they are present only in those locations and how their distribution will change through time.

Biogeographic studies may range in spatial scale from continental to individual watersheds, estuaries, or even smaller areas. A single study may encompass several spatial scales to understand the distances over which ecosystem components interact, or they may focus on a single scale to identify the specific details of a particular organism's distribution or other system component. Biogeographic studies may also include a range of time scales which may resolve changes in habitat or species distribution on daily, monthly, seasonally, or even on much longer scales. The scale and resolution of biogeographic studies is often subject to logistical, financial, and technological limitations. Financial and personnel allocations determine the amount of time that can be spent in the field collecting fine-scale information. As a result, the final extent and detail of the biogeographic data used in any study is typically customized to carefully balance logistical constraints while meeting the specific issues and objectives relevant to that locality.

B. Application Of Biogeographic Concepts To Aid Sanctuary Management

The system of National Marine Sanctuaries encompasses a mosaic of seascape components, oceanographic conditions, and geomorphological features that include coral reefs, kelp forests, whale migration corridors, deep sea canyons, and even underwater archeological sites. They range in spatial extent from one-quarter square mile in Fagatele Bay, American Samoa to over 5,300 square miles in Monterey Bay, California. Despite vastly different management objectives and seascape features, all sanctuaries are responsible for managing spatial resources and activities. To properly manage these resources, sanctuary staff require a thorough understanding of resource distribution relative to Sanctuary boundaries.

Biogeographic analysis is an ideal tool for sanctuary managers to utilize for conservation of biodiversity and ecosystem integrity across the spectrum of spatial and time scales that these issues encompass. Even basic biogeographic data layers are lacking in many sanctuaries, such as a simple inventory of organisms and habitat that the sanctuary was designed to protect. Completing a biogeographic assessment of the distribution of such resources within and across sanctuary boundaries is critical for placing them into their wider ecological context and to understanding how the ecosystem composition changes through time. This baseline information is central to all management decisions and is the foundation for more sophisticated analyses. Coupling data layers on the distribution of animals and their habitats with data on human and natural threats provides a powerful analytical tool for managers of those resources. Using the biogeographic approach, managers can explore the potential changes in resource distribution that result from alternative management practices. Scenarios of interest may include, a better awareness of possible effects of an oil spill on sanctuary resources, understanding the impact of marine zoning within National Marine Sanctuaries, or the alteration of current MPA boundaries or regulations governing the resources of a given sanctuary and the surrounding areas (Fig. 1). The ability to conduct ecological forecasts across the range of spatial and temporal scales encountered by Sanctuary managers is a valuable asset when answering inquiries regarding the expected impact of proposed regulations, conveying the trade-offs in resource use among multiple interest groups, and in generating public support during the often contentious period of public comment that precedes changes in management practices.

C. A Focus On Diverse Management Needs

The goal of this five year effort is to bring a biogeographically based approach to the management of natural resources within the National Marine Sanctuaries. More specifically, this effort will be incorporated into the management plan review process for each applicable National Marine Sanctuary (Table 1). Significant areas of this review process where biogeographic analysis can support information needs and decision making include: environmental characterizations, boundary evaluations, zoning, and threat assessment.

To successfully establish a biogeographic approach to management in the National Marine Sanctuaries, two objectives must be addressed. First, an assessment of current information holdings and a prioritized list of data needs must be completed for each sanctuary. Second, for this assessment to have lasting benefits, the ability to repeatedly collect, manipulate, and analyze biogeographic data must be established at each site. This will be achieved by conducting a collaborative biogeographic study, bringing together the NMSP and NCCOS staff to address a specific management issue at each Sanctuary.

II. REPRESENTATIVE BIOGEOGRAPHIC ASSESSMENT

The text below describes representative results from implementation of the biogeographic approach that can be applied to each applicable National Marine Sanctuary (Table 1). The initial biogeographic assessment outlined in the five-year NCCOS/NMSP plan was implemented in the spring of 2001 to conduct a 24-month investigation to assess biogeographic patterns of selected marine species found within and adjacent to the boundaries of three contiguous West Coast National Marine Sanctuaries (Fig. 2) [11]. These sanctuaries, Monterey Bay, Gulf of the Farallones, and Cordell Bank, are conducting a joint review to update sanctuary management plans. To support the management plan review process, the Biogeography Program is leading a partnership effort to conduct a robust analytical assessment to define important biological areas and time periods within the region. Phase I of this project was recently completed and it provided data, analytical results, and descriptions of ecosystems and their linkages; it also identified data gaps, and suggested future activities now underway in Phase II [12].

Phase I of this effort was a biogeographic assessment of

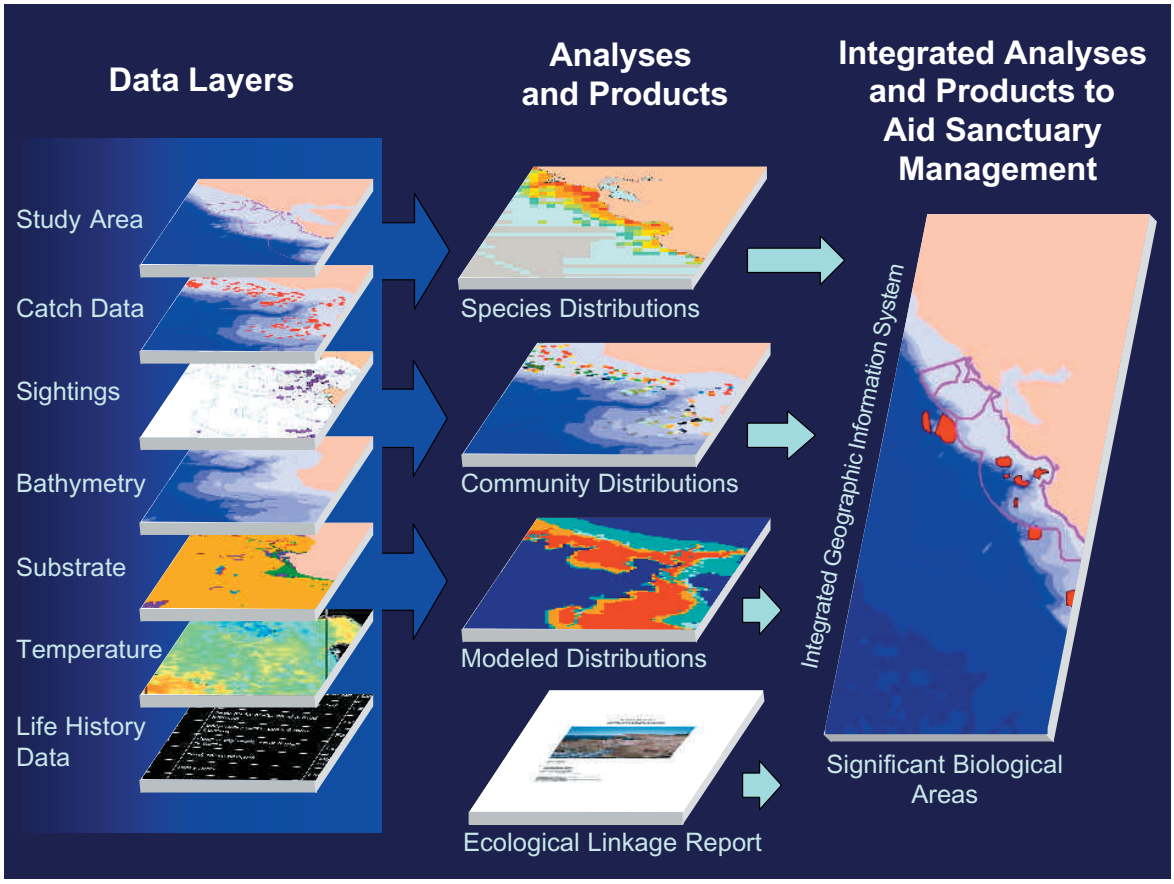

Fig. 1. Generalized biogeographic approach to study NOAA National Marine Sanctuaries.

existing data on the distribution and abundance of marine fishes, marine birds, marine mammals and their associated habitats. The study did not attempt to define biogeographic patterns along the entire U.S. West Coast nor in very near-shore environments (e.g., estuaries). Rather, the study area was restricted to the marine area from Point Arena in Mendocino County (38˚54'32" N, the northern bound) to Point Sal in northern Santa Barbara County (34˚54'05" N, the southern bound). This relatively large study area enabled the assessment to extend beyond the limits of current sanctuary boundaries to place study results in the context of north/cental California Coast biogeographic patterns. Results of this assessment are being used to assist the NMSP in addressing issues such as evaluating potential modification of sanctuary boundaries and changes in management strategies or administration, based on the principles of biogeography.

The biogeographic assessment was formulated around three closely integrated study components: (1) an *Ecological Linkages Repor*t, (2) biogeographic analyses, and (3) development of GIS data for incorporation into NMSP's Marine Information System (MarIS) (Figs. 1 & 3). The majority of results from the assessment were presented as a suite of GIS maps to visually

TABLE 1. Status of biogeographic studies at NOAA National Marine Sanctuaries

NMS Site	Biogeographic Activity	Status
Monterey Bay	Biogeographic Characterization	Underway, Year 2
Gulf of Farallones	Biogeographic Characterization	Underway, Year 2
Cordell Bank	Biogeographic Characterization	Underway, Year 2
Gray's Reef	Benthic Habitat Mapping	Completed
Fagatele Bay	Benthic Habitat Mapping	Underway
NW Hawaiian Is. CR Ecosystem Reserve	Biogeographic Characterization	Underway
Channel Islands	Boundary Alternative Assessment	Underway
Stellwagon Bank	Biogeographic Data for Management Plan Review	Underway
Olympic Coast		TBD
Florida Keys		TBD
Flower Garden Banks		TBD
Hawaiian Islands Humpback Whale		TBD
Monitor NMS		TBD
Thunder Bay		TBD

Fig. 2. Locator map of entire study area from Point Arena to Point Sal. National Marine Sanctuary boundaries shown in red.

display biogeographic patterns across the study area. The body of the document provided examples of the entire suite of digital map products found on a companion CD-ROM. The spatial data and additional information, such as digital species distribution maps and additional details on analytical methodologies, were also presented on the CD-ROM.

The overall project process, milestones, and associated time frame are shown in Fig. 3. The text below provides an overview of each of the study components and examples of associated biogeographic products to demonstrate the types of information that can be generated across the system of national marine sanctuaries.

Ideally, biogeographic assessments utilize significant amounts of data that have been collected over the entire spatial extent of

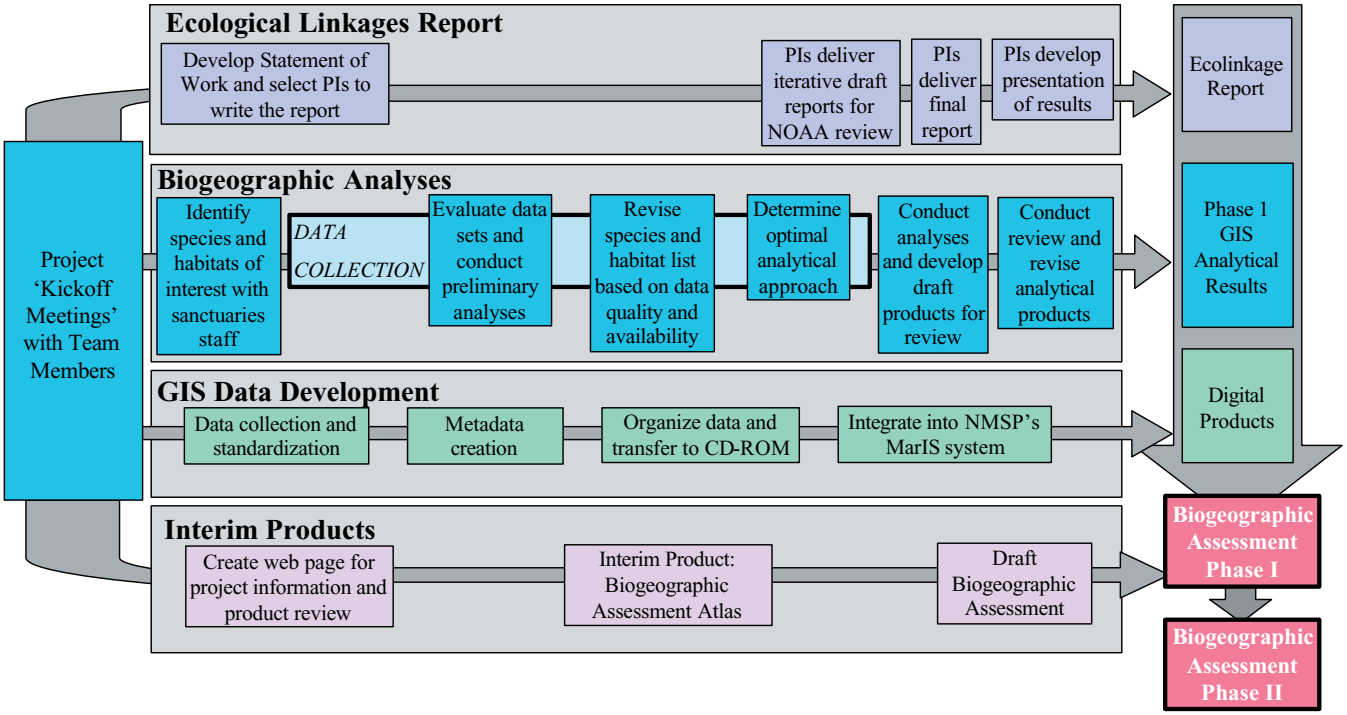

Fig. 3. Biogeographic process for assessment of marine resources off North/Central California: supporting updates to management plans for Cordell Bank, Gulf of the Farallones, and Monterey Bay National Marine Sanctuaries.

the study area over a long time period. However, such a wealth of data is rarely available. In many instances, little information exists to accurately characterize the study area or associated living marine resources. This paucity of comprehensive data can limit the efficacy of biogeographic assessments, but additional analytical methods can be used to complement the assessment. In addition to analysis of databases, two additional tasks were used to conduct the assessment. First a synthesis of existing information was compiled and presented in an *Ecological Linkages Report* to provide background information on species, habitats, and a general ecological characterization of marine ecosystems and linkages within the study area. Second, species habitat suitability modeling was conducted for fishes to define potential species distributions based on known habitat affinities and physiological limitations [6].

In addition, a critical component of the assessment process was the extensive effort to have the data, analytical approaches, and results peer reviewed. Initial analytical results were presented to experts familiar with the marine ecosystem off north/central California, as well as to the originators of the data sources, in an attempt to improve the analyses [11]. The role of expert review and input was considerable, and the contributions made by experts significantly enhanced the assessment. Thus, the integration of the synthesis of ecological linkage information, statistical analyses, species habitat suitability modeling, and peer review resulted in this biogeographic assessment product.

A. Study Components

1) Ecological Linkages Report

The *Ecological Linkages Report* provides the context to understand overall biogeographic product results, relative to the biogeography of the U.S. West Coast [13]. The bulk of the report describes ecosystems in the region, key species associated with these ecosystems, ecosystem status, and linkages among them. The report presents the latitudinal range distributions of species groups, such as invertebrates, fish, marine birds and marine mammals. These maps provide an overview of marine species' distributions along the entire west coast of North America by documenting the accepted northern and southern range endpoints of species that occur in all or part of this region. In addition, the report identifies gaps in current knowledge about regional ecosystems.

2) Biogeographic Analyses

This study component introduces the methods used to conduct the assessment and the results of the biogeographic analyses. This component of the assessment is the cornerstone of the overall biogeographic product to support the NMSP joint management plan review process. The data, analyses, and supporting information are linked using statistical and GIS tools to portray in space and time significant biological areas or "hot spots". The term "hot spot" is defined based on specific criteria or metrics (e.g., species diversity, high species abundance). The vast majority of the analytical results are displayed as a series of maps to visualize where the analyses identified biologically significant areas.

There are many different ways to analyze and organize biogeographic information; however, to efficiently support the management plan process, only a limited number of analytical options were invoked. These analyses were selected based on reviewers' comments on the Project's Interim Atlas Product [11], feedback from technical review meetings, and peer review workshops. Thus, a very difficult step in the project was to select and rely on the most appropriate analyses to characterize the various components of the marine ecosystem that exist in the study area. The inclusion of the GIS-based products on the companion CD-ROM will enable NOAA staff, advisory councils, and research partners to query data and information relevant

for questions and issues that are not specifically addressed in this product.

The first analyses focused on a suite of assemblage analyses to assess the biogeography of fishes and a few macro-invertebrates. Primary data included fisheries-independent data, such as those collected by researchers from the National Marine Fisheries Service (NMFS) (Fig. 4), and fisheries-dependent data, such as those collected by the California Department of Fish and Game for recreational fisheries. These data sets, although not spatially or temporally comprehensive, are the most robust data sets that exist for the entire region, and provide considerable information on the distribution of several hundred fish and invertebrate species.

a) Species Habitat Suitability Models

Due to limitations in the spatial and temporal extent of data and to complement the assemblage analyses of fishes, species habitat suitability index (HSI) models were developed [6]. This was done primarily to accommodate the paucity of empirical data in near-shore areas and to target species of special significance to the sanctuaries. An extensive literature review of the life history characteristics of individual species resulted in information on species' habitat affinities that were converted into quantifiable habitat suitability index values [7]). The life history information and associated species habitat suitability index values are found on the CD-ROM. These derived values were input into an equation and used to predict potential distributions based on an affinity for the mosaic of bathymetry and bottom habitats found throughout the region (Fig. 5). The species habitat suitability models were validated through statistical and spatial analyses, using fishery-independent survey data.

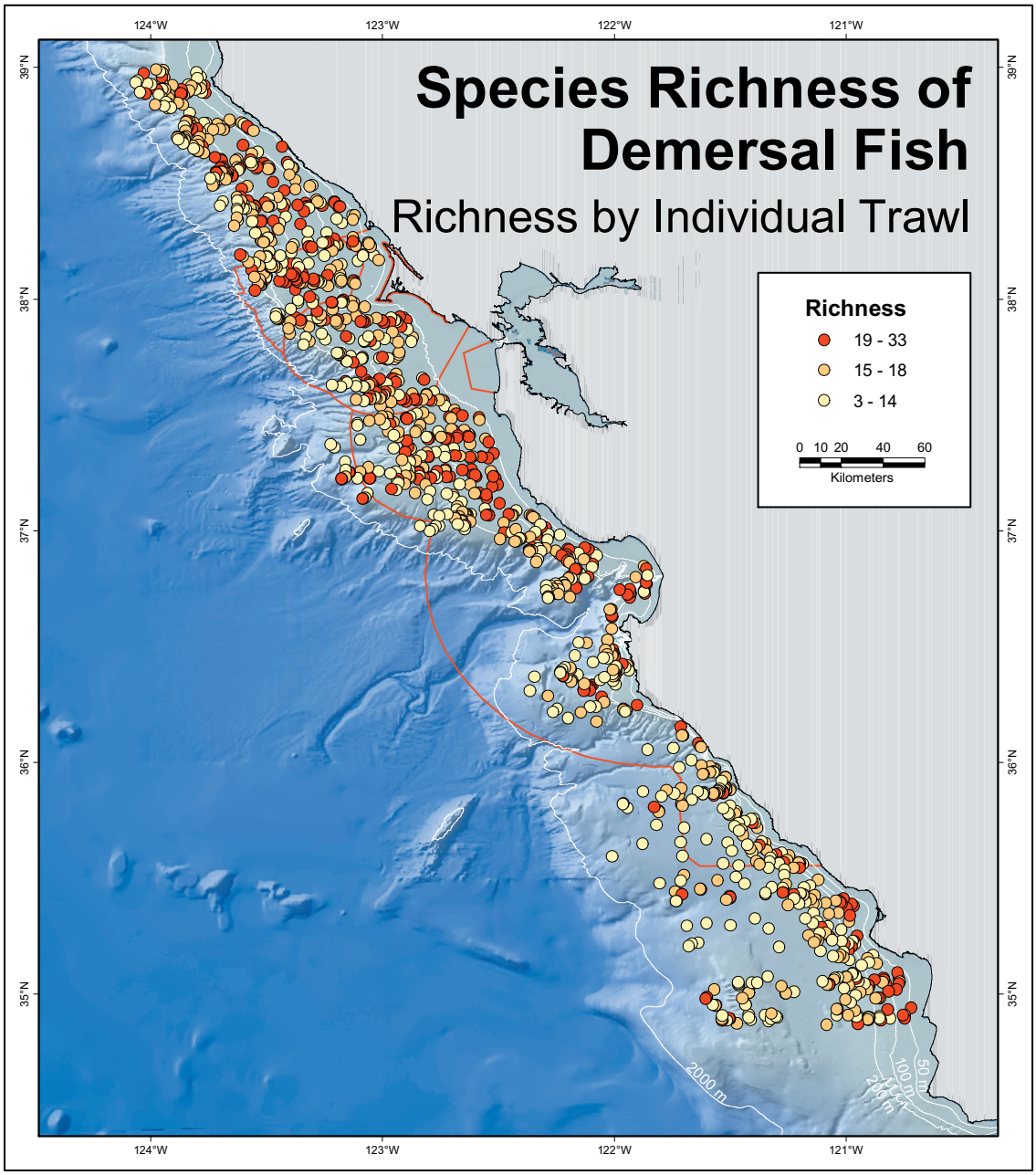

Fig. 4. Species richness of demersal fish from individual NMFS shelf and slope trawls.

b) Marine Birds

The Biogeography Program contracted H.T. Harvey & Associates and R.G. Ford Consulting to define and assess biogeographic patterns of marine birds found within the study area. These experts used multivariate statistical methods and GIS to develop a series of maps that displayed seasonal marine bird distributions, estimated densities, and diversity (Fig. 6). The results are reported as maps (i.e., hot spots) and associated data tables to visualize important locations and time periods for marine birds in the study area. Phase II of the assessment will present a robust technical report on the methods and results summarized in the Phase I map and tabular products.

c) Marine Mammals

The Biogeography Program contracted H.T. Harvey & Associates and R.G. Ford Consulting Co. to work with the project team and local marine mammal experts to identify biogeographic patterns and important areas and time periods for marine mammals occurring in the study area. In addition, NOAA/NMFS scientists provided marine mammal sightings data along the entire West Coast to aid in analyzing marine mammal biogeographic patterns relative to the study area. These experts used a GIS to develop a preliminary series of maps that show occurrence patterns and important areas and time periods for 13 marine mammals in the study area. Phase II of this assessment will incorporate additional data, include additional marine mammal species maps, and map selected community metrics. A robust technical report on this work is also planned.

3) Integration Analyses

Many possible combinations of the data layers could be integrated for the biogeographic assessment. In most instances, however, it was not appropriate to integrate all results across taxa. Therefore, to minimize confounding of results and to focus on the "protection of biodiversity" component of the NMSP mission, the integration of patterns in species diversity

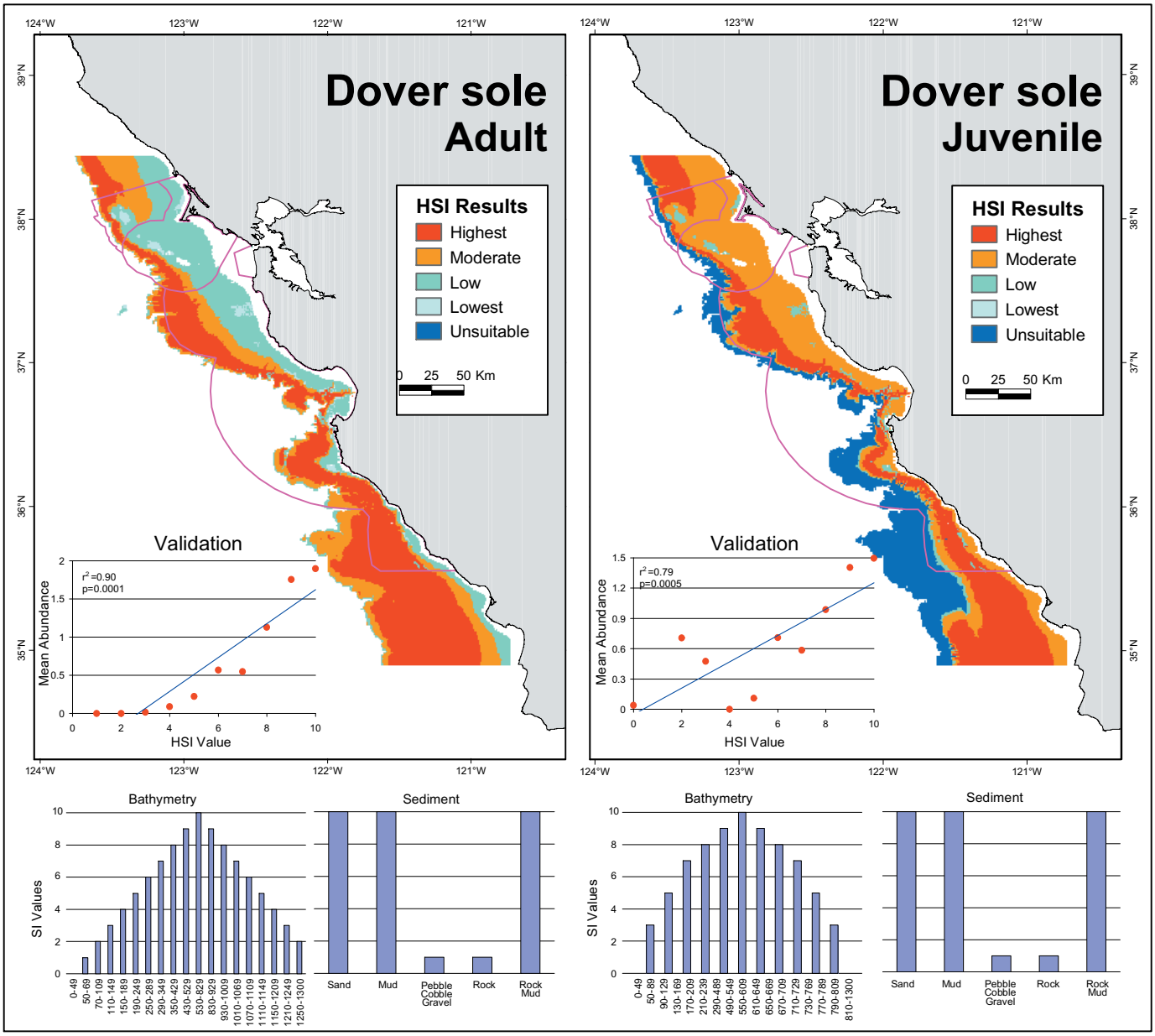

Fig. 5. Potential distribution of habitat suitability for adult and juvenile Dover sole. Map inset contains validation statistics, and Suitability Index values for bathymetry and substrate are displayed below the maps.

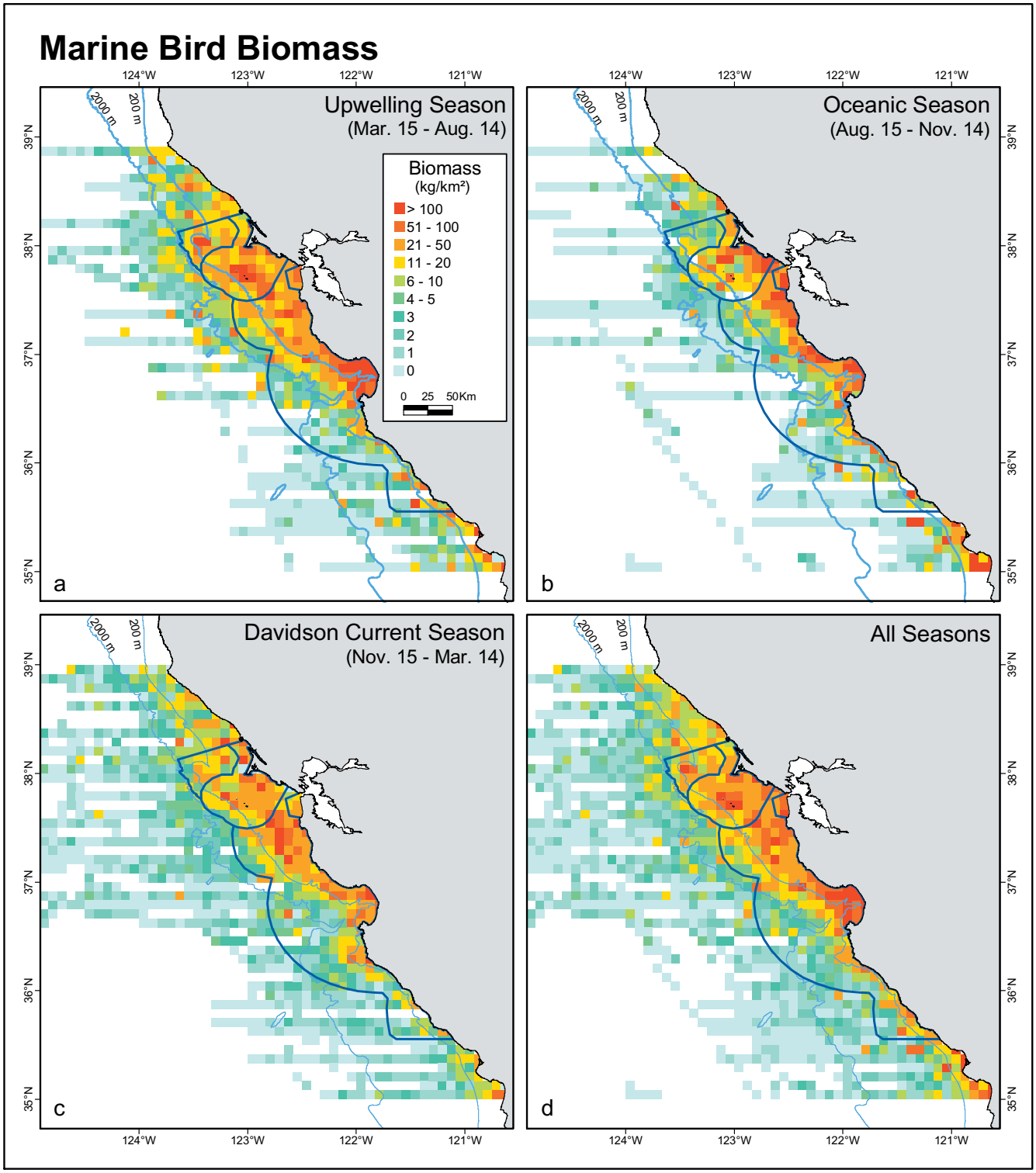

Fig. 6. Marine bird biomass, by season and for all seasons in study area.

and density was utilized to define biologically significant areas across species groups. In addition, results of individual species habitat suitability models were integrated across species. Thus, an approach was developed to integrate individual species habitat suitability models into a single cumulative suitability metric indicating areas of high potential groundfish abundance. These results were coupled with fish and marine bird metrics to define a map of integrated biological hot spots (Fig. 7). In an attempt to achieve the most explanatory and informative integration of the diversity and cumulative suitability results, analyses were conducted to detect recurring spatial patterns that were present among the multiple species groups. Thus, areas that showed significant biological concentrations, high species diversity, or usage by multiple species groups were delineated. These areas of significant biological importance contributed to defining and assessing biogeographic patterns within the study

area (Fig. 7).

III. CONCLUDING COMMENTS

Spatially explicit biogeographic assessments provide a robust set of analytical results and GIS data to strengthen the sustainable management of marine resources within and adjacent to the National Marine Sanctuaries. A primary use of the biogeographic assessments will be to support the NMSP as it continues to conduct management plan reviews and updates for all National Marine Sanctuaries. In addition, the Biogeography Program will assist the NMSP in further analyses and presentations of the data and analytical results to address specific research and management questions. Plans are to continue to implement the biogeographic approach across all National Marine Sanctuaries as described in Kendall and Monaco [1].

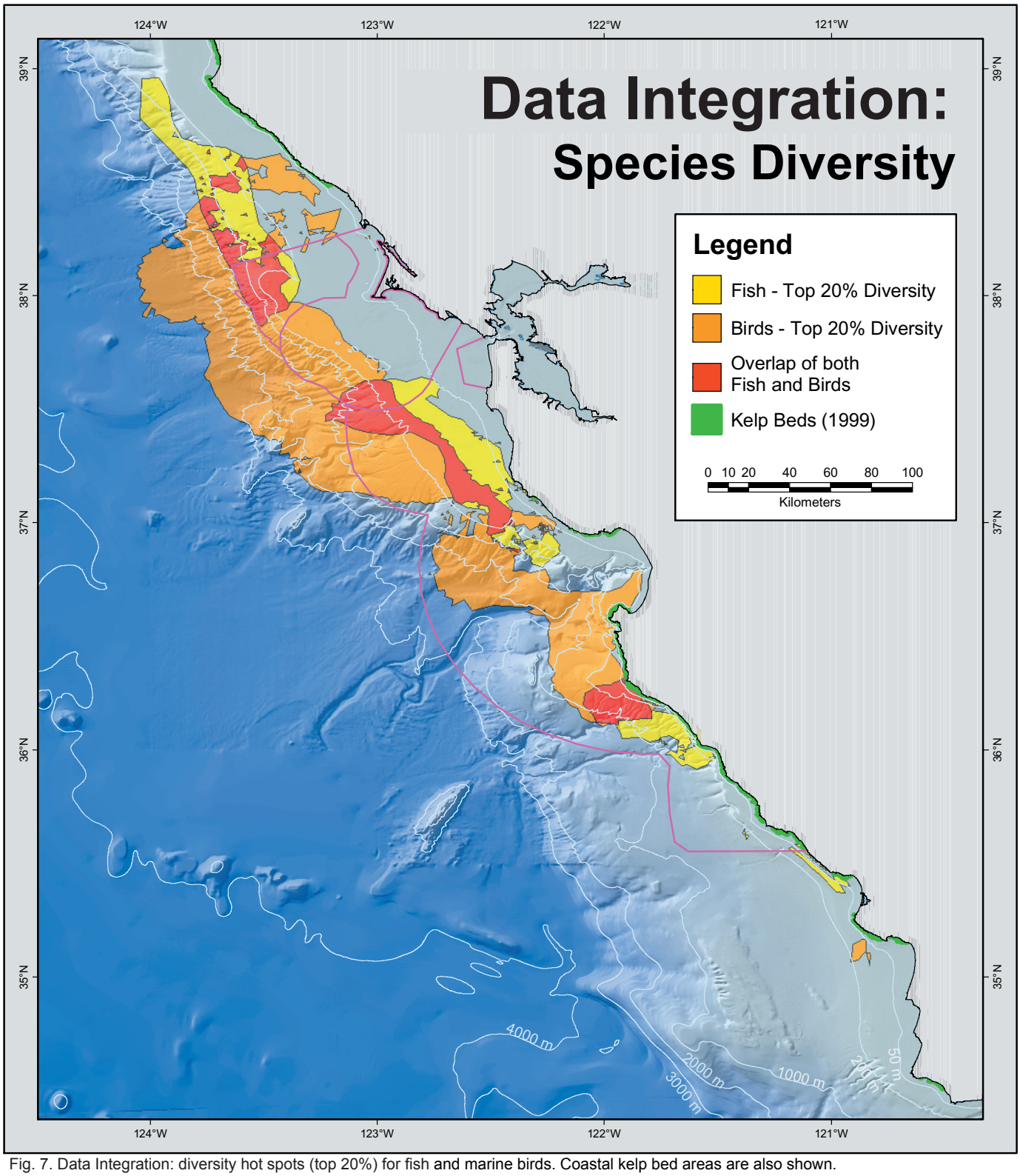

Fig. 7. Data Integration: diversity hot spots (top 20%) for fish and marine birds. Coastal kelp bed areas are also shown.

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